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DESIGN 2010

AN INFORMATION REQUIREMENT STRATEGY FOR CAPTURING AND ANALYSING DESIGN ACTIVITY AND BEHAVIOUR

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Keywords: Empirical Issues, Research Methods, Capture Framework

1. Introduction

This paper forms part of the wider ongoing discussion on the issues and possible mitigating techniques present in empirical design research today. Indeed it is widely acknowledged that there are many diverse methods available to the empirical researcher. There are also a number of ways in which these can be compared or controlled. Ultimately, however, all of these techniques aim to develop some form of rigour, validity, replicability and understanding in the wider design research community. This paper brings these discussions together acknowledging their differences but also drawing out a number of fundamental similarities in order to identify and address the key barriers to success. Further it goes on to argue that these fall into an overarching theoretical frame from which common factors and issues can be identified and recognised. This is then used to structure the argument for a broader understanding and reporting of contextual and social factors while also offering a more focused discussion of empirical information gathering and experimental planning. This discussion is intended to act as an overview of the issues an empirical researcher must be aware of and to offer some guidance of how they can start to address these data collection and validity issues as part of their experimental design. The paper is also aimed at bringing together and moving forward the discussion on what constitutes good empirical research, what its influences are and how design research as a community can set about mitigating them. The paper focuses on the research and methodological aspects of design research. In this way design in industry is affected indirectly through improvements in design research quality.

2. Empirical Research

Empirical studies in design research are approached in many different ways. Although the approaches are many and varied there is often a common relationship to other disciplines where these approaches have also been used and developed. Examples of such symbiosis between design research and other fields can be typified by the use of applied ethnography, quasi-experiments and cognition studies. Although these are frequently adapted to the needs and uses of the design research community there is an ongoing debate as to their relevance to the real design situation. Central to this debate are a number of key issues facing all types of empirical design research as used today [Cash*, et al.* 2009]. The combined effect of these issues is to cause a disconnect between empirical findings and the research they support [Lloyd*, et al.* 2007].

A review of empirical literature has revealed that although the issues faced by empirical design research are numerous many of them have been discussed at length in fields such as education research, social science and ethnography. For example, approaches such as applied ethnography, quasi-experimentation, common data analysis and common methods are all based on the techniques

discussed in these fields. It can therefore be argued that much can be gained from further understanding and learning from the methodological issues faced by these contributing fields. A notable example of this mirroring of methodological issues is the discussion of the lack of research uptake in industry (in this case clinical) due to factors such as generalisability, relevance of empirical findings and lack of replication by Glasgow [2007]. Although other unique factors have been discussed it can be seen from Glasgow's work that many of the problems encountered map directly to design research problems as discussed by Lloyd *et al.* [2007], Cash *et al.* [2009] and others [Gray*, et al.* 1998, Kitchenham 2002].

Using this as a starting point for a review of empirical techniques, several common features were identified that are relevant to the majority of empirical research methods used by design researchers. These are linked to the idea that the primary goal of empirical research is to understand the real situation through studies. A secondary goal of empirical research was also identified from the community perspective, namely, providing the basis for reuse, re-evaluation and retrospection through the development of rigour and methodological robustness.

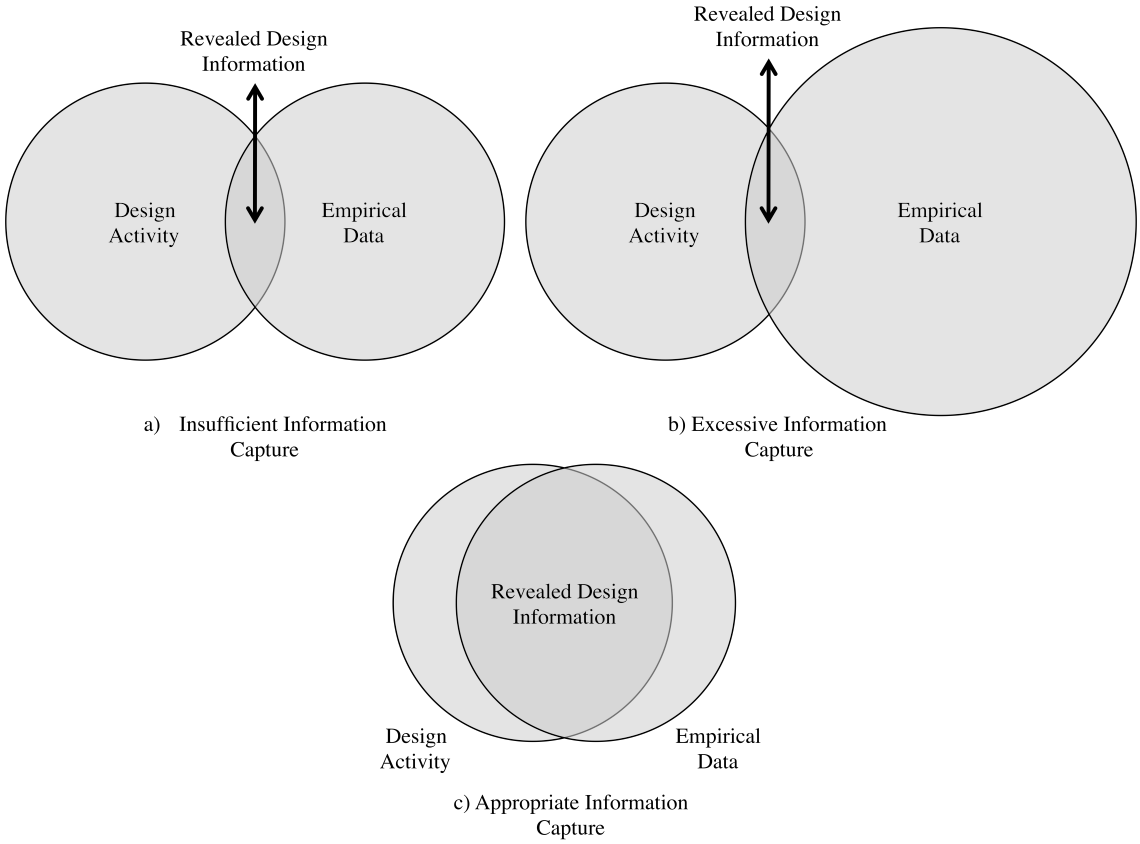

Figure 1: A representation of issues and aims of empirical design research: a) Insufficient information capture, b) Excessive information capture, c) Appropriate information capture

Figure 1 characterises the different theoretical possibilities encountered in the literature. The overlapping circles represent the information embodied in the design activity, the information captured empirically and the information revealed to the researcher about the design activity. It should also be noted that Figure 1 is intended to demonstrate changing proportions rather than relative amounts as it can be seen that the scope of the design activity is vast compared to even the most thorough study. Given the relation in Figure 1 two adverse situations arise common across all the empirical literature reviewed:

- Insufficient appropriate information captured.
- Excessive inappropriate information captured.

Insufficient information (see Figure 1 (a)) capture can be characterised as a lack of appropriate data concerning either the design activity or the other contextual factors required for the two goals of

empirical research. These can be caused through lack of resources, access, planning or simply a lack of understanding of appropriate techniques. Examples include failures to capture or control certain empirical aspects such as the six areas identified by Kitchenham [2002], or factors such as self-reflection, intensity and richness as discussed by Ball [2000]. Further examples of insufficient capture are identified by Gary and Salzman [1998] in their discussion of factors affecting empirical validity. There are also a number of more specific issues that are driven by insufficient empirical information such as the idiosyncrasy of method development and deployment making validation, replication or reuse extremely difficult [Goetz*, et al.* 1981]. *Excessive information* (see Figure 1 (b)) capture can be characterised as excessive inappropriate data being captured due to lack of planning or full understanding of subsequent additional requirements that then go unfulfilled. Lloyd *et al.* [2007] highlight this as a critical problem in studies where it increases complexity and can result in confusion. Goetz and LeCompte comment on this as a detrimental factor due to the limited time and resources available to the researcher [Goetz, et al. 1981] while Kitchenham and others note the importance of focused experimental design in order to guide statistical analysis and its potential to damage statistical validity in some analysis regimes [Kitchenham 2002].

Finally, Figure 1 (c) represents an idealised vision of empirical data capture. This has been characterised as the appropriateness of the captured information. This represents a study that gathers accurate information focused on the design activity while also providing sufficient information relating to the context, methods, environment and other empirical factors required for reuse. This can be seen as the ideal scenario described by Kitchenham [2002], Goetz [1981] and others. The previous sections argue that there are a number of overarching issues in relating design research to empirical findings. It further argues that a key element in addressing these issues is the data / information capture and in particular the appropriateness and extent of capture.

3. The Empirical Framework

The issues described in Section 2 can be considered as elements of the more complex overall empirical framework. This includes the planning, carrying out, analysis and reporting of empirical research. The idea of appropriateness of empirical information for idea implementation and reuse can be used to decompose the area into a number of interrelated factors. This framework is developed from the different aspects of performance and reuse developed throughout the literature and is one part of a much larger more complex framework representing the wider scope of empirical design research.

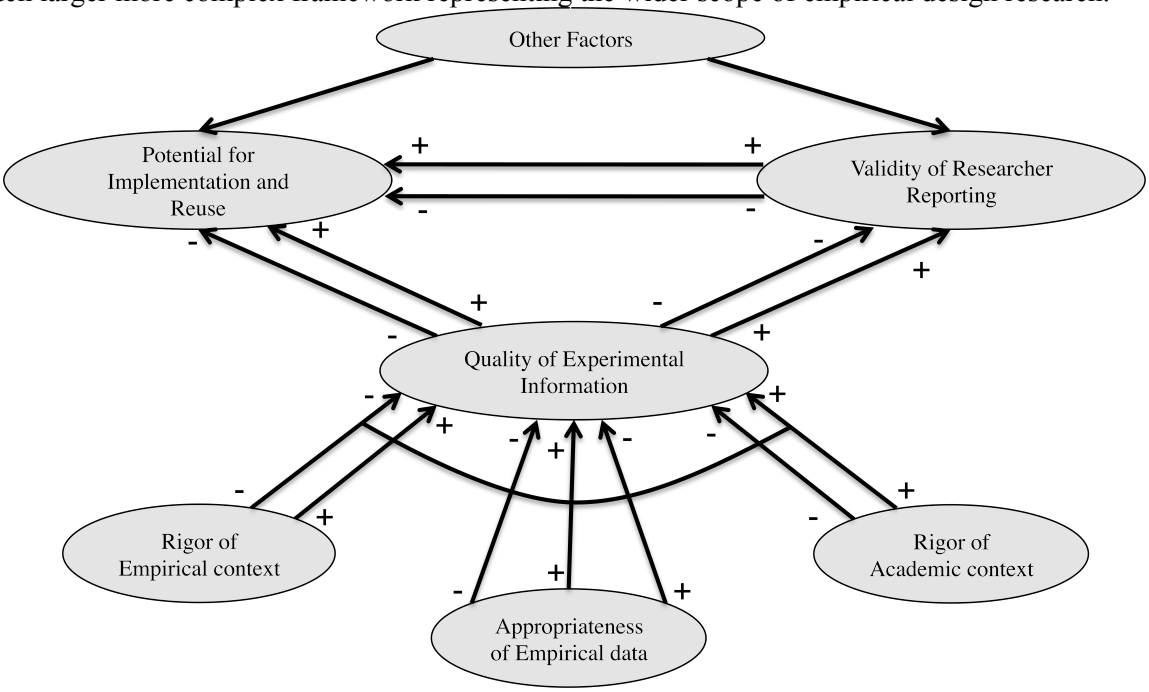

Figure 2: Reference Model Diagram showing the multiple input factors affecting the quality of experimental information and its wider implications for implementation and reuse

Figure 2 presents a *Reference Model Diagram* [Blessing, et al. 2009] of the empirical research situation. It identifies three core areas that affect the quality of empirical research: the rigour with which empirical context is defined, the appropriateness of the empirical data and the rigour with which academic/researcher context is defined. These areas encompass the issues identified in section 2 and appear to present a almost universally acknowledged influence structure for empirical studies in fields as diverse as clinical research [Glasgow 2007], ethnography, applied ethnography and cognition [Ball 2000], social science [Adelman 1991] and engineering [Cash, et al. 2009, Kitchenham 2002].

Figure 2 also shows the relationships between input factors and output affect [Blessing, et al. 2009], for example insufficient empirical data is represented by the negative – negative relationship [Adelman 1991] between appropriateness of empirical data and quality of experimental information while excessive inappropriate information is represented by the positive – negative relationship [Lloyd, et al. 2007]. Similarly, relationships between different dimensions are shown, the linking line joining the three core areas represents their interdependence [Adelman 1991, Hemmelgarn 2006]. Without rigourously defining the empirical context, environmental and social influences, it is difficult to adequately characterise empirical information. Adelman [1991], Lloyd [2007], Ball [2000] and others argue for the use of multiple techniques and triangulation in order to build richer more appropriate data sets thus addressing the issues represented by the relationships.

Finally, Figure 2 offers a basic representation of how quality feeds into application by individual researchers and the wider community. These two elements represent the two goals of empirical study, namely, to describe a situation or activity (individual) and support replication, reuse and implementation (community). There are also a number of influence factors outside the scope of this work, *other factors,* such as social interactions, perceptions and attitudes within the research community itself.

From this discussion and its embodiment in Figure 2 it is possible to identify the link between the factors represented by context and the factors representing empirical capture. It is also important to note that improving any one of these three core areas offers the potential for incrementally improving the overall situation. Thus this paper focuses on the empirical information aspect while also discussing the importance of developing the other two factors and what the empirical researcher can do to develop this relationship when choosing empirical methods or techniques.

3.1 Empirical Factors

There are several areas that must be considered before selecting the empirical factors to be captured during an empirical study. Gray and Salzman [1998], Kitchenham [2002], Goetz and LeCompte [1981] and others argue for rigourous statistical methods supported by effective experimental design and focus, identifying the importance of using multiple complimentary techniques in increasing the statistical validity of findings. In addition to the development of better statistical techniques through experimental design they also highlight the significance of standardisation of research techniques and measures. Cash *et al.* [2009] also discusses the importance of standardisation in tackling many of the issues facing empirical design research. From this it can be seen that a critical element when carrying out an empirical study is to understand the capture interfaces, sources and techniques during the design phase. The importance of the experimental design phase is also identified by several other authors [Adelman 1991, Gray, et al. 1998] who highlight its critical role in the development of validity and rigour. It can also be seen that if ideas such as standardisation and validity are to be developed they must be discussed prior to the actual study.

To this end developing an improved understanding of information requirements and a structured approach to specifying the information capture strategy can be seen as a step towards achieving these goals. In addition to this, providing the researcher with a more structured approach in which to consider their study allows them to clearly consider all the available options from which empirical measures can be built. Through this structured information strategy researchers can plot a multitude of capture paths before selecting those most appropriate to the influence mechanisms under consideration. In this way it is possible to mitigate both excessive and insufficient information capture by developing the researchers awareness of the appropriateness of the different capture paths. It also allows the researcher to identify techniques that may otherwise have not been considered in order to

circumvent obstacles such as restricted access to information or to indentify multiple complimentary techniques for the triangulation of methods.

3.2 Contextual Factors

In addition to the empirical factors considered in Section 3.1 there is a large amount of extra information required if a study is to have relevance and meaning outside of its specific research context [Ball 2000, Hemmelgarn 2006]. In order for a research community to build on individual studies a large amount of common contextual and methodological information is required to support the empirical findings. Kitchenham [2002] discusses this at length with regards to software engineering and provides a series of guidelines highlighting the importance of contextual information for the reuse of research. Not only are many of the points raised in Kitchenham's article directly applicable to design research it can be seen that there is a growing need for such guidelines to be developed within this area. It does however highlight the importance of contextual information in framing of empirical findings and the important role this plays in developing the relevance, applicability and validity of empirical research.

In addition to this, contextual information is vital for the development of baseline datasets, which can be considered from multiple perspectives. This has been partially explored by Lloyd *et al.* [2007] as part of the common data analysis method where the ability to develop multiple perspective relies on the empirical and contextual richness of the original data captured. Further to this Hemmelgarn [2006] notes the importance of these contextual factors as potential vectors for revealing unique insight which would not otherwise be developed through the use of the raw empirical data alone. The relevance of these issues in design research is highlighted by the current lack of replication, validation and reuse endemic within the design research community [Cash, et al. 2009].

In conjunction with the identification of these issues it should be noted that through the combination of qualitative and quantitative techniques far richer more rigourous data sets can be developed while still offering the researcher a high degree of flexibility within a standardised framework of methods and measures [Ball 2000, Goetz, et al. 1981, Gray, et al. 1998]. Based on these findings it is argued that a concerted effort must be given to the discussion, identification and dissemination of the contextual factors required by the research community for implementation and reuse. As discussed in Section 3.1 standardisation is a critical factor in the success of such efforts and without the development of a common understanding of these contextual factors empirical research will continue to be limited in its scope and affect [Adelman 1991, Glasgow 2007, Goetz, et al. 1981].

4. The Information Requirement

As discussed in Section 3.1 standardisation and triangulation are important concepts in the development of rigour and validity in empirical data gathering. Hansen *et al.* [2001] highlight the complexity of product development research and the subsequent lack of a qualitative accumulation of research findings. Hansen *et al.* go on to propose an ontological approach to tackling this problem. They propose a series of objects: Actor, Activities, Information, Artefact and Environment through which they aim to qualify the whole of the product development research field. In this case each object is split into main and sub attributes with the aim of fully categorising all the possible concepts applicable to the object. It can be seen that such a categorisation-based approach addresses factors such as standardisation and communication and through these the accumulation of research findings. Though the ontology proposed by Hansen *et al.* provides an excellent tool for communication and development it is not, however, a practical experimental design tool in its current form.

Given the aforementioned limitations and the issues discussed in Sections 2 and 3 the remainder of this paper develops an information requirement strategy for capturing and analysing empirical data with the intention of being a practical research aid. The aim being to allow the researcher to quickly and easily identify all the different available capture paths available to them while retaining a degree of standardisation, which addresses aspects of communication, standardisation and triangulation. Further, it is proposed that when used in conjunction with tools and concepts such as ontological approaches and the assessment of contextual factors, the researcher is more able to fully develop,

define, communicate and validate their work while providing for a heightened level of community validation, replication and reuse.

Table 1: Synthesis of empirical information sources and techniques

<table>
<tr><th>Interaction
Interface</th><th>Information
Source</th><th>Capture
Technique</th><th>Analysis
Type</th></tr>
<tr><td>Out of Designer</td><td>Source</td><td>End Capture</td><td>Analysis</td></tr>
<tr><td>audiovisual
chart
emotional
physical
pictorial
text inc. code
verbal</td><td rowspan="3">audiovisual files
body language
conditions local
conditions social
conditions specific
document
designer
device com.
device working
expressions
prototype
physiology
program
repository
scraps
sketches
space local
space social
space specific
system
virtual env.
unstructured notes</td><td>digital scan copy
versioning
digital AV copy
mapping
physical model
reflection
reproduction
summary coding</td><td>activity
annotation/mark-up
behaviour
coding
classification
cognitive
decisional
discourse
interaction
keyword
language
meta-analysis
protocol
workflow</td></tr>
<tr><td>In Designer</td><td>Concurrent Capture</td><td>Indexing/ Organising</td></tr>
<tr><td>emotional
influence social
influence process
influence goal
memory</td><td>audiovisual
discon. verbalisation
discon. photo
discon. description
field notes
logging activity
logging e-xxx
logging location
monitoring computer
monitoring program
verbalisation</td><td>annotation semantic
annotation user defined
indexing manual
indexing passive
indexing automatic
PDM systems
multi-faceted - classification</td></tr>
<tr><td colspan="4">Some Analysis Examples/Tools</td></tr>
<tr><td colspan="4">Analysis
Activity based analysis of CAD use – Campbell 2007
Decisional process – Montagna 2008
Latent semantic analysis – Dong 2005
Annotation and mark-up of logbooks – McAlpine 2006

Indexing/Organising
Qunidi tool – Rosenschein 2004
Waypoint – McMahon 2004
Infonic – 2009 and Virage – 2009</td></tr>
</table>

Table 1 represents an embodiment of a practical structured approach to experimental design that aims to develop both standardisation and triangulation. Table 1 focuses on the empirical factors as outlined in Section 3.1 and has been developed from a review of existing empirical literature and a series of empirical studies carried out over the last two years at the University of Bath Innovative Design & Manufacturing Research Centre (I*d*MRC) (see Section 4.1). The approach offers the researcher a tool for identifying appropriate capture and analysis mechanisms for an empirical study. When considered in conjunction with the contextual factors discussed in Section 3.2 the approach allows for greater standardisation and simpler communication of methods. In addition to these possible benefits it allows the researcher to clearly map the empirical capture conditions and identify possible information shortfalls or issues before commencing a study. For example, this could allow a researcher to rapidly identify the feasibility of possible capture options when faced with restrictions such as those encountered in some company environments. In addition to this aspect, once multiple feasible options have been identified it allows a researcher to quickly select complimentary methods and outputs, thus developing triangulation of techniques.

Table 1 presents a sequential view of the experimental design process starting with the identification of input and output interfaces such as audiovisual and textual. Once the capture interfaces have been identified the possible information sources are reviewed. It is possible to have multiple sources for a single interface, encouraging the researcher to consider the full range of possibilities for each interface. The selection of sources can be driven by experimental restrictions or through the assessment of the different possible outputs. For example, an experimental restriction on capturing audiovisual recordings eliminates certain information sources immediately or a restriction on the outputs based on a desired analytical technique may render particular sources inappropriate. Once information sources have been identified it is possible to look at their different capture mechanisms and subsequently the various analysis methods.

Adopting an iterative approach it is possible to narrow down the scope of what capture path is most appropriate for the given conditions and desired post analysis outputs. It is also possible to use the current selection stage (for example *Information source*, Table 1) to help inform the choice of the pervious stage (for example, *Interaction interface*, Table 1). In this way it is possible to initially select a number of capture techniques that are available and thus instantly discard several information sources that cannot be captured with the selected mechanisms. A typical example of such a situation would be the dictation that the only capture method available is field notes due to privacy issues in a company. This mandate would make it very difficult to thoroughly and accurately capture sketches, textual information, expressions *etc.*

The concept that standardisation and triangulation allows clearer communication, validation and reuse is supported through the approaches use of a series of defined factors while the simplicity and linearity support its use as a practical experimental design tool. Thus through dissemination it can be seen that such a tool could lead to wider reuse of research findings, clearer communication of methods and so on as discussed in Section 3. The critical factor in this process is, as with all methods, building a base of researchers actively using and developing it. Without this dissemination and development such an approach cannot hope to address the wider identified issues of reuse, standardisation and communication. Thus it is important and strongly advocated by the authors that our peers open this concept up to discussion and contribute to the development of a standard overarching framework for such a structured approach.

4.1 Example Studies

Two example studies have been developed to help clarify the applicability of the proposed approach and also demonstrate its usefulness as both a planning and retrospection tool. The studies used for these examples form part of a series of empirical studies conducted at the University of Bath I*d*MRC over the last two years. They have been selected in order to demonstrate the flexibility and other identified uses of the tool as discussed in Section 4. For the purposes of these examples the analysis type column of the approach has been neglected for clarity and restrictions on space.

Example Study 1 – Industrial Ideation Tools

This study was carried out in an industrial setting where the researcher had been given full access to the companies' engineers with no restrictions on recording. The researcher was, however, restricted to working within the existing organisational process and was thus not able to contrive 'experimental' situations but was free to introduce new tools, techniques *etc*. into existing situations. The researcher's focus was on the affect of introducing different pictorial stimuli to a brainstorming activity. The researcher then clearly defined the number and quality of ideas generated during the meeting as their success criteria. From this overview it can be indentified that the empirical input variable is pictorial information and in this case PowerPoint slides. From the success criteria it can be noted that the output material could be in several different forms. Matching these inputs and outputs with the framework in Table 1 reveals the possible capture paths given in Table 2. Also shown in Table 2 are the actual paths used by the researcher denoted by the italicised entries.

Table 2 shows a review of a number of the possible capture paths the researcher could use to examine the inputs and outputs. From this it is possible to quickly identify several areas that may have been able to give additional information to the researcher or could have been used to triangulate the research findings. In addition to this, it allows the researcher to clearly identify their selected path and relate this to the other possible routes. For instance, in this case, the researcher had access to the designers so could have employed reflective techniques to assess their interpretation of idea success. However concurrent verbalisation would not have been appropriate due to the large numbers of designers involved in the brainstorming activity. From this it can be seen that from the purely empirical information perspective this study can be characterised as having insufficient appropriate information.

Table 2: Inputs and output capture paths for example study 1

	Interface	***Source***	***Capture***
Inputs	*Pictorial*	*Document (.ppt)*	*Digital scan copy* Audiovisual
Outputs	*Pictorial* Text inc. code Verbal Memory	*Audiovisual files* *Document (.ppt)* Designer Repository Scraps *Sketches* Unstructured notes	*Digital versioning* Reflection Reproduction Summary coding *Audiovisual* Discon. Verbalisation Discon. Photo Field notes Logging e-xxx Verbalisation

Example Study 2 – Lab Based Information Inputs

This study was carried out in a design lab setting where the researcher had full control over the capture technologies employed. The research focus was on assessing the affect of different types of information input using video, spreadsheets and a combination of the two including explanations. The success criteria for performance included number, effectiveness and relevance of the ideas generated. From this, the inputs can be identified as audiovisual, chart and text. Based on the experimental setup of group sketching the output interfaces can also be identified as pictorial, text, verbal, *etc*. and are set out in Table 3.

Table 3 again reveals the various options available to the researcher and highlights those actually used in italics. As with the previous example it is possible to identify several methods of assessing input effectiveness the researcher did not cover, for example, the lack of reflection on its effect on the designers' goals or perception of the problem. It is also interesting to note that despite several additional methods being available for specifically examining the affect of the inputs on the outputs such as reflection they have not been applied in favour of broader less focused techniques such as

audiovisual. From this lack of triangulation it could be surmised that the researcher was unclear as to their intended measures and research questions and thus gathered and analysed a great deal of inappropriate information rather than using a number of more focused techniques. The lack of focus identified here has proved to be true in the researchers subsequent analysis phase where there has been a relative lack of direction and a high degree of confusion as to what the desired metrics are and how they could be accounted for. Thus this study could be characterised as having excessive inappropriate information.

Table 3: Inputs and output capture paths for example study 2

	Interface	***Source***	***Capture***
Inputs	*Audiovisual* *Chart* *Text inc. code*	*Audiovisual files* *Document* *Program*	*Digital versioning* *Digital AV copy* Field notes Logging activity Monitoring program
Outputs	*Pictorial* Text inc. code *Verbal* Influence – social Influence – goal Memory	*Audiovisual files* Designer Scraps *Sketches* Space specific Unstructured notes	*Digital scan copy* Reflection Reproduction Summary coding *Audiovisual* Discon. Verbalisation Discon. Photo Field notes Logging e-xxx Verbalisation

5. Conclusions and Further Work

This paper has discussed the important role of empirical studies in addressing the issues associated with empirical design research. Based on these issues and a review of existing empirical literature the importance of developing the appropriateness of empirical information is argued. In particular, two possible adverse scenarios were identified, namely, excessive inappropriate information and insufficient appropriate information in terms of their ability to aid the researcher in characterising the design activity. Developing this concept further the dimensions of the overall empirical framework that are critical to the generation of quality empirical research are developed and the role of appropriate empirical data gathering is further discussed. In addition to this, two other factors were identified as critical to empirical research quality. These were the rigour with which researcher and empirical context was considered and reported. The contextual factors and their relationship to the gathering of appropriate information were then discussed, highlighting their critically interlinked nature and the need to address all three in order to improve reuse and implementation. In addition to this the idea of standardisation for communication and reuse was identified as a key concept.

The paper then focused on the development of an information strategy for improving the standardisation and appropriateness of empirical information capture. The strategy outlined here forms the first step in a larger dedicated research program and will be empirically developed and refined. This took the form of a structured approach outlining the possible capture interfaces, sources and techniques available to the researcher. From this it was discussed how the empirical researcher could use such a approach to identify different and complimentary capture paths. Several arguments for this strategy were put forward including, identifying critical requirements, introducing a level of standardisation and supporting triangulation of methods. Two retrospective examples were then used to show the different possible mechanisms available, the flexibility and the usefulness of the information requirement strategy as a practical tool. These examples supported both the concept developed in Sections 2 and 3 of appropriateness of empirical data and the idea of the information strategy as a practical tool for the researcher. In addition to these factors the importance of community wide discussion, development and dissemination of such concepts was also highlighted and critically

linked to the concept of developing standardisation for reuse, communication and replication. The paper took a research and methodological focus, aiming to affect industrial design work by improving the quality of design research throughout the wider community. The ideas discussed in this paper also aim to bring together and move forward the current debate on empirical research strategies and what it means to produce good quality empirical research. Despite the widely acknowledged issues in empirical design research it seems clear that there needs to be a discussion of the underlying barriers to experimentation and how these can be addressed by both the wider community and the individual researcher. These factors will be developed and refined as part of the ongoing development of the strategy and assessed through empirical testing later in the development process. This paper offers one framework through which these can be classified and considered. However, it is recognised that wider input is needed and indeed essential if any common understanding is to be reached. Building on this the authors invites our peers to contribute and develop this framework as cross-validation and community wide participation is a crucial step in taking this work beyond its initial usefulness as a practical structured approach to the design of empirical studies.

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